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Book of Abstracts
November 2-5, 1998

Kellie Ann Beall, Editor

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Near-Surface Vapor Bubble Layers in Low Stretch Burning of PMMA

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Abstract

Experiments on large-scale buoyant low stretch stagnation point diffusion flames over a solid fuel (PMMA) have been conducted over a range of stretch rates of 2-12 sec^{-1}, which are similar to low gravity flames [Olson, 1997]. During the experiments, an extensive layer of material above the glass transition temperature is observed, due to the low burning rates (low Peclet numbers). Unique phenomena associated with this extensive glass layer include substantial swelling of the burning surface, in-depth bubble formation and migration and/or elongation of the bubbles normal to the hot surface. Bubble layers can be a source of flow as the bubbles pop at the surface of the burning material (fuel vapor jetting and/or ejection of burning globules). This self-induced flow caused by the bubble layer enhances the burning of materials at low stretch .

Background

Materials which degrade in-depth to form bubbles as they burn have been shown [Kimzey, 1986; Olson and Sotos, 1987; Yang et al, 1997] to be a generate a flow (fuel vapor jetting or ejection of burning globules), which enhances burning in a quiescent microgravity environment through viscous entrainment of fresh oxidizer. Models which include in-depth degradation and bubble formation [Wichman, 1986; Butler, 1997] have been developed, but to date no quantitative model is available. The near-surface molten polymer and bubble layers in burning PMMA are very complicated. There are property variations with the glass transition. The in-depth degradation chemistry processes involved in bubble layer development are not fully understood.

Experiment

The experiments are conducted with a cylindrical flame configuration with different radii PMMA samples (2.4 cm thick) to vary the stretch rate. A large radius is required to establish low stretch rates [$a \propto (g/R)^{1/2}$ for buoyancy-induced stagnation point flow]. The range of stretch rates of interest is 2-12 sec^{-1}, which correspond to approximate radii of 5 - 200 cm. The oxidizer is simply room air.

Sample Swelling and Regression Transients

The position of the surface was measured from video of the experiment as a function of time for thick PMMA samples in a buoyant low stretch geometry, in order to measure the actual regression rate as a function of time. The regression rates were lower than previously obtained [Ohtani et al. 1981], due to the low stretch rate.

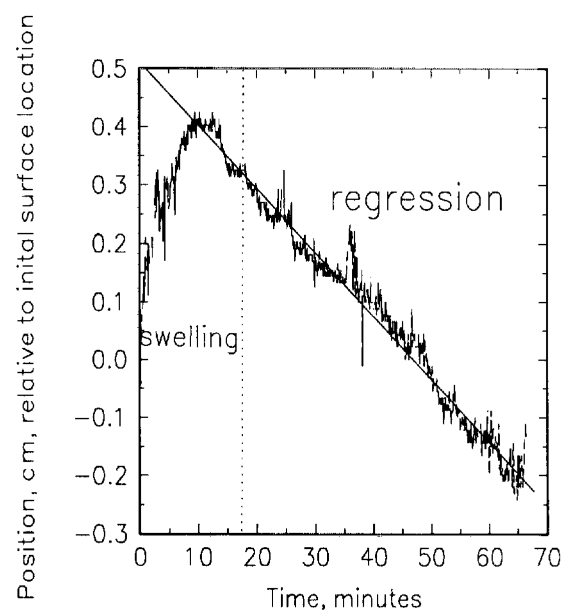

Figure 1: Swelling and regression data.

It was noted from these measurements that the sample surface swelled outward significantly during the early phase of the experiment. This was attributed to the development of the bubble layer during the ignition and solid-phase heatup of the sample. Swelling stopped as the bubble layer became fully-developed and regression began to dominate the surface motion. An example of this swelling and regression is shown in Figure 1. During the early phase, the surface swells outward (4 mm in this case) before regression is observable. Time scales of this period are of the same order as the solid-phase heatup timescales.

The initial swelling of the sample was unexpected in these experiments. Although other researchers have described a two-phase layer during combustion [Krishnamurthy and Williams, 1973; Seshadri and Williams, 1978; Ohtani et al, 1981], no one has mentioned this initial swelling. Thermal expansion of the PMMA as it is heated (estimated to be ~0.2 mm) is not sufficient to explain the swelling. Rather, the observed swelling appears to be linked to the bubble layer. The thickness of the bubble layer is measured after each experiment from the cooled, cut, and polished sample, and plotted in Figure 2. Maximum swelling is normalized with the measured bubble layer thickness and plotted in Figure 2 (swelling ratio) as a function of stretch rate. Also in Figure 2, the regression during the swelling phase is estimated from the steady regression rate (see Fig.1), and can be considered as unrealized swelling.

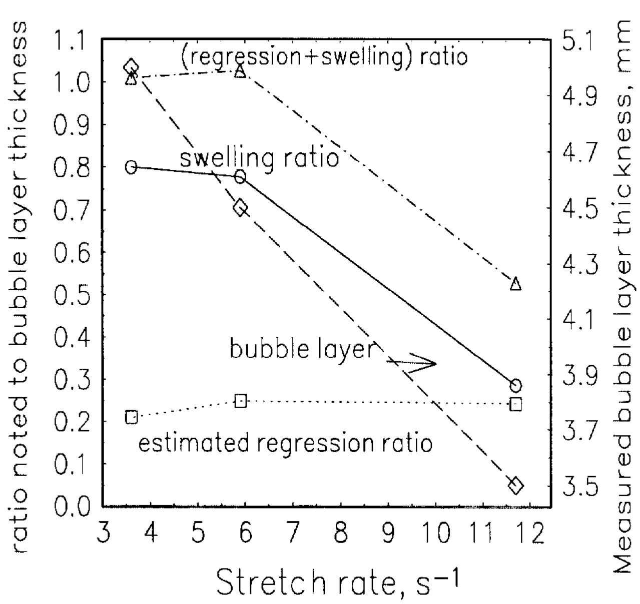

Figure 2: Ratio of swelling to measured bubble layer thickness as a function of the stretch rate.

For larger stretch rates ($a>12\ s^{-1}$), which would be typical of normal gravity experiments, the trend in the data indicates that swelling would be masked by the surface regression, due to the high burning rates. At high burning rates, where the solid-phase Peclet number is large (Pe>3.6), the heated layer is thin. This explains why the swelling due to the bubble layer has not been observed in previous investigations. The combined swelling and regression normalized by the bubble layer thickness approaches unity as stretch rate is reduced, until unstable flame coverage occurs below stretch rates of 3 sec^{-1}. The initial total swelling (swelling+regression) is thus commensurate with the in-depth bubble layer which develops during the low stretch (Pe<1) burning of these samples.

Conclusions

Low stretch buoyant stagnation point combustion of cylindrical PMMA samples have been conducted with the lowest burning rate data obtained for this geometry. The very low regression rate experimental results showed for the first time the sample swelling during the heatup phase of PMMA combustion, and linked that swelling directly to the development of the bubble layer. This swelling is only easily observable when solid-phase Peclet numbers are low (Pe<1). A much more detailed model is needed to describe these processes in the solid phase.

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